



AI-assisted data extraction helps uncover spatiotemporal patterns and socioeconomic drivers of wildlife crime involving sea turtles

Changjian Fu ^{a,1} , Weijia Ren ^{a,1} , Emilio Pagani-Núñez ^{b,c} , Yuqing Han ^d ,
Jincheng Yang ^{e,f} , Huijie Qiao ^g , Zhongqiu Li ^{a,*} 

^a Lab of Animal Behavior and Conservation, School of Life Sciences, Nanjing University, Nanjing, 210023, China

^b School of Applied Sciences, Edinburgh Napier University, Edinburgh, EH11 4BN, United Kingdom

^c Centre for Conservation and Restoration Science, Edinburgh Napier University, Edinburgh, EH11 4BN, United Kingdom

^d School of Life Sciences, Sun Yat-sen University, Guangzhou, 510275, China

^e College of Wildlife and Protected Area, Northeast Forestry University, Harbin, 150040, China

^f State Forestry and Grassland Administration Detecting Centre of Wildlife, Harbin, 150040, China

^g State Key Laboratory of Animal Biodiversity Conservation and Integrated Pest Management, Institute of Zoology, Chinese Academy of Sciences, Beijing, 100101, China

ARTICLE INFO

Keywords:

Hotspot
Illegal trade
Sea turtle
Tortoiseshell
Wildlife crime

ABSTRACT

Crimes associated with an ever-increasing demand for wildlife products are one of the most notable threats to marine and freshwater ecosystems. To combat such crimes, it is crucial to identify their spatiotemporal patterns and hotspots, which have largely been overlooked in previous research. However, especially after the emergence of large language models (LLMs), this process has become more time-efficient and accurate. In this study, we analyzed spatiotemporal patterns and socioeconomic drivers of wildlife crime in sea turtles, using Deepseek to extract data from 247 court verdicts. DeepSeek data extraction reached an accuracy of over 99 % in extracting 25 items from each verdict. We found that most individual sea turtles and products were seized in southeastern coastal cities of China and identified two main trafficking hotspots. First, nearly 73 % (450/613) of the hawksbill turtles and 84 % (325/386) of the green turtles were seized or originated from Hainan province, China. Second, nearly 98 % (207/211) of the loggerhead turtles were seized from Zhoushan, Zhejiang province. Moreover, nearly all the manufactured products (over 99 %, mainly made of tortoiseshell) were seized or originated from Hainan. Destinations of trafficking tended to be northern inland cities, with one main hotspot: 5.5 % (68/1236) of individuals and 30.3 % (8896/29,323) of the products were seized in Xuzhou, Jiangsu province, which originated from Hainan. Our study highlights how AI tools can boost biodiversity conservation research by leveraging large datasets. In doing so, we were able to identify major hotspots of wildlife crime, as well as main trafficking routes. These findings might be relevant for law enforcement efforts and help to enhance sea turtle conservation.

1. Introduction

Marine and freshwater ecosystems are the object of intense extractive pressure due to the demand for wildlife products for all sorts of uses, from medicine to leisure (Hasler and Ott, 2008; Thomas-Walters et al., 2021; Zhou et al., 2021; Vogel and Hoeksema, 2024). Certain uses have been associated with large-scale declines in biodiversity. For example, leisure diving reduces coral cover and has damaged 51 % of the coral

colonies in the dive sites of the coastline of Dahab, Egypt (Hasler and Ott, 2008). Similarly, prayer animal release increases the risk of biological invasions in aquatic ecosystems (Jiang et al., 2016; Du et al., 2024). In particular, wildlife crimes provoked by these diverse demands have become one of the most notable threats to aquatic animals (Aceves-Bueno et al., 2021; Lee and Wong, 2023; Pheasey et al., 2023). From 2015 to 2021, wildlife crimes affected nearly 4000 species and involved 13 million seized products globally, including many aquatic species,

* Corresponding author at: Lab of Animal Behavior & Conservation, School of Life Sciences, the Xianlin Campus of Nanjing University, No. 163 Xianlin Avenue, Qixia District, Nanjing, China.

E-mail addresses: 602022300007@smail.nju.edu.cn (C. Fu), 502024300032@smail.nju.edu.cn (W. Ren), E.Pagani-Nunez@napier.ac.uk (E. Pagani-Núñez), yuqinghan23@gmail.com (Y. Han), maturecheng@163.com (J. Yang), qiaohj@ioz.ac.cn (H. Qiao), lizq@nju.edu.cn (Z. Li).

¹ Changjian Fu and Weijia Ren equally contributed as first authors.

<https://doi.org/10.1016/j.biocon.2025.111511>

Received 12 June 2025; Received in revised form 25 August 2025; Accepted 18 September 2025

Available online 20 September 2025

0006-3207/© 2025 Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

such as seahorses, sea turtles, sturgeons, and sea cucumbers (UNODC, 2024).

These crimes include illegal fishing, hunting, trade, trafficking, and smuggling of individual animals (e.g., pets), their body parts, derivatives, and manufactured products (e.g., luxury), and pose threats to a large number of species (Petrossian et al., 2016; Petrossian, 2018; Thiault et al., 2020). For instance, a total of 170,849 fish specimens were illegally trafficked for ornamental aquariums and were seized in the Brazilian Amazon from 2003 to 2020 (Beltrao et al., 2021). At least 7682 individual shells and 121,391 tons of giant clams (Tridacninae) were seized in Southeast Asia from 2003 to 2022 (Lee and Wong, 2023). Between 2018 and 2021, 74 small-clawed otters (*Aonyx cinereus*) used for the pet or fur trade were seized in 16 incidents in Vietnam (Gomez and Nguyen, 2023). Knowing the factors related to such crimes and seizures is crucial for law enforcement and biodiversity conservation. Nevertheless, the spatiotemporal patterns, hotspots, and related factors of crimes toward aquatic wildlife have traditionally been overlooked, yet ascertaining these patterns is vital to designing crime prevention plans and promoting marine and freshwater wildlife conservation (Keel and Wolf, 2020; Weekers et al., 2020).

Wildlife crimes are generally studied from two main perspectives (Masés-García et al., 2021; Green et al., 2024). On one hand, from the criminal subject perspective, namely the suspects, which generally includes demographic characteristics that are related to the crimes, such as income (Godoy et al., 2010), education (Shao et al., 2021), and gender (Green et al., 2024). On the other hand, from the situational/environmental context of crime perspective, which includes geographical and socio-economic features of certain places where the crimes are located (Ni et al., 2022; Liang et al., 2023). Additionally, according to environmental criminology, crimes converge in time and space (hotspots) (Weisburd, 2015; Sleuwen et al., 2018), which can be leveraged to predict future victimization (Thiault et al., 2020).

Identifying hotspots of aquatic wildlife crime is vital to making prevention plans, especially for countries or regions with complex river systems, multi-island systems, and long coastlines (Petrossian, 2018; Weekers et al., 2020). For instance, illegal fishing activity is more likely to occur in coasts with more valuable and abundant fish species and proximity to viable landing points in Western Africa (Petrossian, 2018). Incorporating these situational/environmental aspects can facilitate more efficient law enforcement and strategies to combat wildlife crimes on a macroscale (Clarke, 1983; Kurland et al., 2018). For instance, it is crucial to reinforce police work in hotspots and dismantle illegal trade routes (Xi et al., 2025). However, extracting key information from large public data sets, including court verdicts, news, reports of seizures, and market surveys, can be very challenging (Siriwat and Nijman, 2018; Hu et al., 2024; Liang et al., 2024). Recently, large language models (LLMs) have become an emerging data extraction tool that can be used to scale up data mining for biodiversity conservation (Raiaan et al., 2024; Reynolds et al., 2025).

In this study, we investigated the spatiotemporal patterns and socioeconomic drivers of wildlife crime in sea turtles using a LLM to aid data extraction. Sea turtles are flagship megaherbivores and have profound impacts on seagrass and coral reef ecosystems (Christianen et al., 2023). However, wildlife crimes threaten sea turtles globally, including the illegal consumption of specimens and shell products for cultural or aesthetic demands (Hainschwang and Leggio, 2006; Lam et al., 2011), luxury meat consumption (Mancini and Koch, 2009), and capturing live individuals for aquariums (Lin et al., 2021). In Costa Rica, sea turtle eggs are illegally harvested and traded to procure drugs (Pheasey et al., 2023). In East Asia, 128 criminal cases were seized from 2000 to 2008, involving 2062 specimens, 6161 products, 919 kg of shells, and 789 shell pieces (Lam et al., 2011). In China, sea turtle consumption has traditionally been important, especially shell products from hawksbills (*Eretmochelys imbricata*) (Ji et al., 2024), which threatens the sea turtle populations living in Chinese waters. In this study, we applied a LLM to process court verdicts about wildlife crimes toward sea turtles in China

in recent decades to assess spatiotemporal patterns and identify hotspots of wildlife crime. We had three main aims:

- (1) Assessing the accuracy of LLM-driven data extraction from court verdicts about wildlife crimes in sea turtles.
- (2) Assessing the spatiotemporal patterns and socioeconomic drivers of wildlife crime in sea turtles, as well as identifying the main hotspots of criminal cases and seizures.
- (3) Assessing smuggling (cross-border) and trafficking (inner) routes and identifying the factors influencing the geographic dynamics of trafficking and the main origin and destination hotspots.

Our study provides geographical patterns and hotspots of wildlife crimes, which can be relevant for future policy-making and incorporated into sea turtle conservation practice in China.

2. Methods

2.1. Study species

Five species of sea turtles can be found in the waters under China's jurisdiction, including leatherback (*Derموchelys coriacea*), loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill, and olive ridley turtles (*Lepidochelys olivacea*) (Wang et al., 2020). Wildlife crimes, as well as habitat degradation, marine pollution, and climate change, threaten sea turtles globally (Hawkes et al., 2009; Lam et al., 2011; Schuyler et al., 2016). In response, the International Union for Conservation of Nature (IUCN, <https://www.iucnredlist.org/>) has listed leatherback, loggerhead, and olive ridley turtles as vulnerable, green turtles as endangered, and hawksbill turtles as critically endangered. These species have also been listed in the Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, <https://cites.org/>). On February 1, 2021, all five species of sea turtles were upgraded from second-class to first-class protection in the "List of Wild Animals under Special State Protection" in China (National Forestry and Grassland Administration, 2021).

2.2. Data collection and cleaning

To achieve our aims, we collected court verdicts about wildlife crimes, including illegal smuggling, trade, trafficking, and hunting. We downloaded the openly accessible Chinese court verdicts from Openlaw (<http://openlaw.cn/>), which Open Law Alliance, a non-governmental organization, has established. This database includes all verdicts from January 1, 2014, to January 1, 2024. Some verdicts before 2014 were also included, but were not comprehensive, while some verdicts after January 1, 2024, could not be accessed from Openlaw due to update delays. We created a keyword search list, including 'sea turtle (海龟, in Chinese)' and Chinese common names of the five species: leatherback (棱皮龟), loggerhead ('红海龟' or '蠟龟'), green turtle (绿海龟), hawksbill (玳瑁), and olive ridley turtle (丽龟). We then developed a web crawling tool using Selenium (<https://www.selenium.dev/zh-cn/>) that automatically downloaded 571 verdicts. We also applied the keywords to the Chinese government's official court verdict database, the China Judgements Online (<https://wenshu.court.gov.cn/>), to collect the verdicts still not included in Openlaw ($n = 13$). All the 584 verdicts were obtained on February 21, 2025.

We screened and removed invalid verdicts in two steps. First, we excluded 167 duplicated verdicts based on the unique verdict number assigned to each criminal case by the courts. Second, we excluded 170 invalid verdicts according to two rules: (1) 127 verdicts that did not refer to wildlife and the term 'sea turtles' appeared in the verdicts as the names of locations, nicknames of criminal suspects, or other humans involved in the cases; (2) 43 verdicts that referred to sea turtles but involved burglary instead of direct wildlife crimes. A total of 247 verdicts remained after removing 337 invalid verdicts.

2.3. Data extraction

We extracted 25 items from each verdict, including:

- (1) the city where the seizures were conducted;
- (2) the number of criminal units, such as a company, an institution, or an organization, which is involved in crime;
- (3) the number of criminal suspects;
- (4) the date of the seizures;
- (5) the date of the crimes;
- (6) the type of wildlife crime (smuggling, trade, trafficking, or hunting);
- (7) whether the crimes were conducted online or offline (yes/no), such as online trade;
- (8) trafficking routes (the origin and destination);
- (9) transportation, such as airplane, truck, or parcel post;
- (10) species (labelled as “unknown” if the species were not identified in verdicts);
- (11) life history stage of the seized individual sea turtles (juvenile/adult);
- (12) the total quantity of individuals, products, turtle shells, or tissues involved in cases, namely, those that could be proved by evidence such as photos or seizures;
- (13) the total legal value of individuals, products, turtle shells, or tissues involved in cases (yuan, RMB);
- (14) the number of individual sea turtles involved, including live individuals, intact bodies, and specimens;
- (15) the legal value of individual sea turtles involved (yuan, RMB);
- (16) the number of products involved;
- (17) the legal value of products involved (yuan, RMB);
- (18) the weight of turtle shells or tissues involved (kilogram);
- (19) the legal value of turtle shells or tissues involved (yuan, RMB);
- (20) the number of seized individual sea turtles;
- (21) the legal value of seized individual sea turtles (yuan, RMB);
- (22) the number of seized products;
- (23) the legal value of seized products (yuan, RMB);
- (24) the weight of seized turtle shells or tissues (kg);
- (25) the legal value of seized turtle shells or tissues (yuan, RMB).

We collected these items using both manual and artificial intelligence (AI) extraction. Manual extraction was conducted by Changjian Fu, while AI extraction was conducted using DeepSeek-R1 (<https://www.deepseek.com/>) by Weijia Ren. To avoid busy requests in DeepSeek, we deployed the model hosted on Siliconflow (<https://siliconflow.cn/zh-cn/>) to Chatbox (<https://chatboxai.app/zh>) through application programming interface (API) requests. To reduce redundancy and stabilize the analysis, we set the temperature value (0–2, a key hyperparameter in LLM) as 0.6 (<https://github.com/deepseek-ai/DeepSeek-R1>). To extract data from verdicts, we created prompts within DeepSeek-R1.

2.4. Prompt defining and extraction accuracy assessing

We defined prompts (Supplementary material 1) for data extraction using DeepSeek based on six criteria. First, to further identify invalid verdicts that were ignored during data cleaning, we asked DeepSeek to discriminate whether the verdicts were related to wildlife crimes. Second, based on the above 25 items, we defined basic prompts to ensure all the data was extracted from each verdict. Third, we introduced examples for each item to promote extraction accuracy. For example, for item (12), the total quantity of individuals, products, turtle shells, or tissues involved in cases, we provided the following example: “such as 100 adult green turtles and two juvenile hawksbills”. Fourth, DeepSeek sometimes speculated that the data was not accessible, therefore, we asked DeepSeek to only extract data from the provided verdicts. Fifth, we also attempted to extract data from several verdicts using DeepSeek

to identify other aspects that needed to be highlighted to optimize the prompts. Finally, DeepSeek has input and output limitations of 64,000 tokens (the basic unit in natural language text, https://api-docs.deepseek.com/zh-cn/quick_start/pricing), and the corresponding word limitations in Mandarin Chinese depend on different verdicts. Some verdicts exceeded the limitations, so we segmented them using PyPDF2 (<https://pypi.org/project/PyPDF2/>) in Python 3.11.7 and input them to DeepSeek sequentially. Each section was ensured to be read and summarized successfully, leveraging additional prompts (Supplementary material 1). Once all segments were processed, we applied the prompts to complete data extraction. The model was required to output data excluding those cases that had already been extracted (Supplementary material 1).

To assess the accuracy of DeepSeek and manual extraction, we compared the 25 items recorded from each verdict extracted using the two methods. If an item did not match between the two methods, we checked the original verdicts to decide which one was accurate. We then counted the number of inaccurate items and calculated extraction accuracy for both methods. Some items included more than one piece of information within one verdict. For example, the seizures from one item included three dates, and the related seized products included three numbers. For these items, if one of the three dates or numbers was inaccurate, we considered the entire item as inaccurate. If the seizures of locations were from different cities within a single verdict, we considered these seizures as different criminal cases. For example, one verdict included three seizures from three cities, so we considered this verdict as three separate criminal cases.

2.5. Geographical and socioeconomic factors of geographical patterns of wildlife crimes

We included 339 prefectures, namely all the prefectures of China, including 292 prefecture-level cities, 30 autonomous prefectures, 7 prefectures, 3 leagues (special prefectures from Inner Mongolia Autonomous Region), 4 municipalities, and 3 counties directly under provincial control. The verdicts did not record seizures in two special administrative regions, Hong Kong and Macao, nor in Taiwan province. To assess the drivers of the recorded crimes and seizures, we selected six geographical and socio-economic factors (Table S1):

- (1) Per capita GDP of each prefecture (pGDP), which was extracted from statistical yearbooks from each prefecture (such as the Beijing Municipal Bureau of Statistics, <https://tj.beijing.gov.cn/>) or the China Economic Information Data (CEIdata, <https://ceidata.cei.cn/>). We first assigned each case to the different prefectures (from 2012 to 2023), then assigned the year of seizures to each case, and finally assigned the corresponding per capita GDP. Lots of prefectures do not record criminal cases, so we assigned these prefectures with years generated randomly (from 2012 to 2023) and then assigned the corresponding per capita GDP. Only in this way can the subsequent analysis be carried out.
- (2) Coastal city (CC, yes = 1, no = 0), which was extracted from the China Marine Statistical Yearbook (National Marine Data Center, https://mds.nmdis.org.cn/pages/ocean_message.html#95).
- (3) International border city (BC, yes = 1, no = 0), which was extracted from the Central People's Government of the People's Republic of China (https://www.gov.cn/test/2006-07/14/content_335831.htm).
- (4) City tier (CT), extracted from the Ranking of Cities' Business Attractiveness in China 2023 (<https://www.datayicai.com/report/detail/999638>), comprised six categories: Tier 1 City = 6; New tier 1 city = 5; Tier 2 city = 4; Tier 3 city = 3; Tier 4 city = 2; Tier 5 city = 1.
- (5) Longitude (Lon), and (6) latitude (Lat) of each Chinese prefecture, which were extracted based on the standard China map GS

(2024)0650 (National Platform for Common GeoSpatial Information Services, <https://cloudcenter.tianditu.gov.cn/>).

2.6. Data analysis

We ran three models to assess how geographical and socioeconomic factors affected the geographical patterns of the recorded wildlife crimes. We used (1) the occurrence of criminal cases (model 1), (2) the seizures of individual sea turtles (model 2), and (3) the seizures of turtle products (model 3, Table S1) as response variables. Before implementing the models, we centered and scaled all the factors. We also assessed multicollinearity for each model using the variance inflation factor (VIF). All the VIF values were < 2.5 (Table S1), which indicates that there were no multicollinearity issues. For all models, we considered the per capita GDP, border city, coastal city, city tier, longitude, and latitude as explanatory variables and set the year of seizure (from 2012 to 2023) as a random effect (Table S1).

For the first model (model 1), we considered the occurrence of criminal cases in each Chinese prefecture (Yes = 1, No = 0) as the response variable (Table S1). We conducted a generalized linear mixed model (GLMM) with binomial distribution using the R package 'lme4' (Bates et al., 2015; Bates et al., 2025) in R (R Core Team, 2025). Because the response variable was zero-inflated (52.6 % zeros), we also implemented a zero-inflated negative binomial regression (ZINB) using the R package 'glmmTMB' (Brooks et al., 2017), including a conditional (frequencies) and a zero-inflated (occurrences) part. We compared the goodness of fit of the GLMM and the ZINB using corrected Akaike information criteria (AIC_c) (Aho et al., 2014; Liang et al., 2023), and the GLMM was selected as the final model (Table S1).

For model 2, we used the number of seized individual sea turtles per case in each Chinese prefecture as the response variable (Table S1). In this case, we implemented a GLMM with Poisson distribution and a zero-inflated Poisson regression (ZIP) model because the response variable was again zero-inflated (80.3 %, zeros). The ZIP model included a conditional and a zero-inflated part (Table S1). According to their AIC_c, the ZIP was selected as the final model (Table S1). For model 3, we considered the number of seized products per case in each Chinese prefecture as the response variable (Table S1). We first transformed the response variable with $\log(x + 1)$ to enhance heteroscedasticity, and then implemented a linear mixed model (LMM).

To assess the differences between the origin and destination of this illegal trade, we performed a GLMM with binomial distribution. We considered whether a Chinese prefecture was an origin or destination as the response variable (origin = 1, destination = 2), considered the previously mentioned six factors as explanatory variables, and set the year of seizures as a random effect. To enhance the goodness of fit of the model (according to AIC_c), the border city was removed from the final model, because this variable was not significant and did not fit the model very well. All statistical analyses were conducted using R 4.4.3.

3. Results

Our results revealed that 1236 individuals and 29,323 products of sea turtles were seized in China from 2012 to 2023, and most seizures converged in several hotspots in southeastern China.

3.1. Extraction accuracy of Deepseek

In 2.02 % (5/247) of the verdicts, criminal suspects or seizures overlapped entirely with other verdicts, and 3.64 % (9/247) of the verdicts partially overlapped with others. Overlaps among cases could only be identified by manual extraction rather than DeepSeek, because DeepSeek could only analyze one verdict at a time. Besides, 1.21 % (3/247) verdicts involved other turtle species instead of sea turtles, such as the big-headed turtle (*Platysternon megacephalum*), which were identified by both manual extraction and DeepSeek. We identified four

verdicts that did not constitute crime (1.62 %, 4/247, three from manual extraction and two from DeepSeek). In these verdicts, the inculpatory evidence was insufficient or the case had exceeded the maximum number of years to entail criminal responsibility (> 5 years).

We removed the above 21 verdicts and calculated the accuracy of DeepSeek and manual extraction using the remaining 226 verdicts (5650 items in total, namely 226 verdicts multiplied by 25 items). The accuracy of DeepSeek was 99.38 % (5615/5650), with 35 inaccurate items (0.62 %), including nine items about the total value involved in the cases and four items about both seizures' numbers and dates. Among these errors, 51.43 % (18/35) were caused by incorrect parsing, 28.57 % (10/35) by information omission, and 20 % (7/35) by hallucinated outputs. The accuracy of manual extraction was 99.20 % (5605/5650), with 45 inaccurate items (0.80 %), including eight items about the dates of the seizures and five items about the dates of the crimes.

After combining the nine verdicts that partially overlapped with other verdicts, a total of 235 verdicts remained. Only non-overlapping parts of these nine verdicts were used for analysis and considered as independent criminal cases.

3.2. Overview of criminal cases and seizures

The 235 court verdicts involved 241 criminal cases, 384 criminal suspects, 11 criminal units, 2180 individual sea turtles ($n = 103$ verdicts, e.g., specimens, Fig. 1a-b), and 29,364 products ($n = 114$ verdicts, e.g., Fig. 1c-d). The cases involved two leatherbacks, 211 loggerheads, 671 green turtles, 657 hawksbills, one olive ridley turtle, and 638 unidentified sea turtles. The total monetary value involved in cases was 26,020,058.7 yuan (RMB).

From 2012 to 2017, the number of criminal cases remained low, then escalated and reached a peak in 2019, and decreased in 2020. Only one case was reported during 2021–2022, and there was a slight increase in 2023 (Fig. 1e). The types of wildlife crimes included one hunting, 23 smuggling, 44 trafficking, and 217 trade cases. Among these cases, 43 involved both trade and trafficking, and one case involved both smuggling and trafficking. A total of 64 cases referred to online illegal trade, including commercial transactions through WeChat or other online platforms (Fig. 1e).

Of the 235 verdicts, 210 reported the seizures of individual sea turtles, products, or tissues. A total of 95 verdicts reported that 1236 individuals were physically seized from 2012 to 2023 (Fig. 1f-g), including one leatherback, 211 loggerheads (207 were seized in Zhoushan, Zhejiang province), 386 green turtles (133 were seized in Hainan province), 613 hawksbills (381 were seized in Hainan), and 25 unidentified sea turtles. A total of 29,323 products were seized, including 29,321 hawkbill products (99.99 %), mainly tortoiseshell jewelry or garniture (e.g., Fig. 1c-d). Two verdicts reported the seizures of 14,510 and 8896 tortoiseshell products, respectively. Only 13 verdicts reported the seizures of tissues or tortoiseshells, including 128.472 kg raw tortoiseshells and 4151.296 kg tissues of green turtles. A single smuggling case seized 4150.5 kg of green turtle skirts (connective tissue around turtle shells) in 2015 (from Manila, Philippines to Xiamen, Fujian province).

3.3. Factors affecting the patterns of wildlife crimes toward sea turtles

Criminal cases tended to occur in Chinese prefectures with high per capita GDP (estimate \pm SE = 0.615 \pm 0.201, $Z = 3.055$, $P = 0.002$), in high-tier cities (estimate \pm SE = 1.686 \pm 0.226, $Z = 7.452$, $P < 0.001$), and in coastal areas (estimate \pm SE = 0.758 \pm 0.172, $Z = 4.401$, $P < 0.001$, Fig. 2a, Table S2). The three Chinese prefectures with the most case occurrences from 2012 to 2023 were Tianjin (36 cases), Beijing (22), and Xuzhou (22, Fig. 3a, Table S3).

More seizures of individual sea turtles tended to occur in Chinese prefectures in low-tier cities (estimate \pm SE = -0.680 \pm 0.062, $Z = -10.936$, $P < 0.001$), in coastal cities (estimate \pm SE = 0.206 \pm 0.043, $Z = 4.780$, $P < 0.001$), in non-border cities (estimate \pm SE = -0.633 \pm

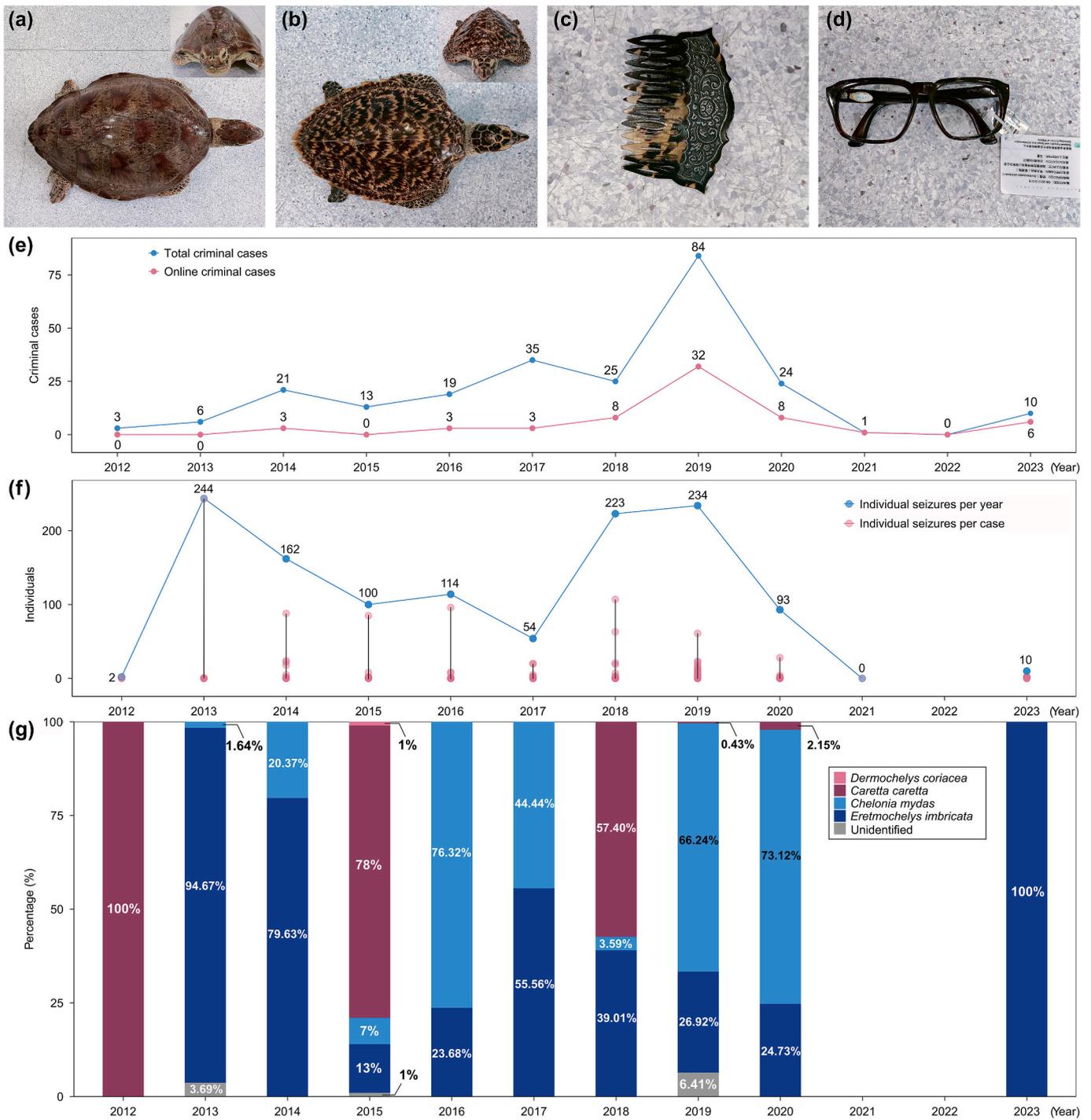


Fig. 1. Examples of sea turtle products and descriptive statistics based on 235 court verdicts (241 criminal cases). (a) Specimen of a green turtle (*Chelonia mydas*). (b) Specimen of a hawksbill (*Eretmochelys imbricata*). (c) A tortoiseshell hair ornament. (d) A tortoiseshell glasses frame. These products are deposited in the State Forestry and Grassland Administration Detecting Centre of Wildlife, Harbin, China (Photo credit: Jincheng Yang). (e) Number of criminal cases each year (total criminal cases) of wildlife crimes and online illegal trade (online criminal cases) from 2012 to 2023. (f) Number of individual sea turtles (including living, dead individuals, and specimens) seized each year or case from 2012 to 2023. (g) Proportions of four sea turtle species seized each year from 2012 to 2023, including leatherback (*Dermodochelys coriacea*), loggerhead (*Caretta caretta*), green turtle (*Chelonia mydas*), and hawksbill (*Eretmochelys imbricata*). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

0.212, $Z = -2.981$, $P = 0.003$), at high longitudes, i.e. eastern cities (estimate $\pm SE = 0.198 \pm 0.080$, $Z = 2.474$, $P = 0.013$), and low latitudes (estimate $\pm SE = -0.213 \pm 0.058$, $Z = -3.651$, $P < 0.001$, Fig. 2b, Table S2). Qionghai (485 turtles), Zhoushan (216), and Xuzhou (90) were the three Chinese prefectures with the highest number of seized individuals from 2012 to 2023 (Fig. 3b, Table S3). 77.94 % of the seized

individuals (378/485) in Qionghai, Hainan province, were hawksbills, while 95.83 % of the seized individuals (207/216) in Zhoushan, Zhejiang province, were loggerhead turtles.

More seizures of products tended to occur in high-tier cities (estimate $\pm SE = 0.455 \pm 0.084$, $t = 5.394$, $P < 0.001$), in coastal Chinese prefectures (estimate $\pm SE = 0.181 \pm 0.064$, $t = 2.842$, $P = 0.005$), and in

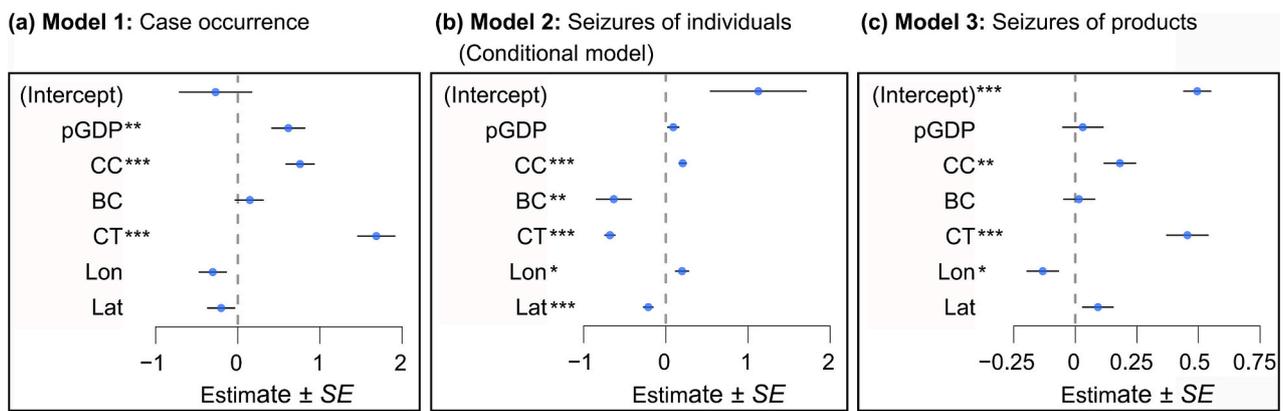


Fig. 2. Results from three models assessing the factors affecting the (a) case occurrence (model 1), (b) the seizures of individual sea turtles (model 2), and (c) seizures of products per case (log-transformed, model 3) in each Chinese prefecture. Coefficient values with 95 % confidence intervals were indicated by estimate \pm standard error (SE). Abbreviations: pGDP, Per capita GDP of each city; CC, Coastal city; BC, Border city; CT, City tier; Lon, Longitude; Lat, Latitude. The negative and positive values of the estimate indicate the negative and positive relationships. Significance: *** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$.

lower longitudes (estimate \pm SE = -0.132 ± 0.064 , $t = -2.051$, $P = 0.041$, Fig. 2c, Table S4). The three Chinese prefectures with the highest number of seized products from 2012 to 2023 were Haikou (12,812 products), Xuzhou (9108), and Guangzhou (3359, Fig. 3c, Table S3).

3.4. Smuggling and trafficking routes

A total of 18 cross-border smuggling routes were reported by 25 verdicts (Fig. 4a-b). A total of 72 individuals, 287 products, and 4246.403 kg tortoiseshells or tissues were seized, mostly from Southeast Asia (e.g., the Philippines, Indonesia, Vietnam), Cuba, and Japan. Most suspects were profiteers and international students. Additionally, a total of 43 trafficking routes were reported within China in 52 verdicts, and 28 of these routes originated from Hainan province (Fig. 4b). Besides the 524 individuals seized in Hainan, 276 individuals seized in other provinces originated from Hainan, including 192 green turtles (69.6 %, 192/276) and 69 hawksbills (25 %, 69/276). The Chinese prefectures where these products originated tended to be coastal cities (estimate \pm SE = -2.549 ± 0.763 , $Z = -3.341$, $P < 0.001$, Fig. 4b, Table S5) and were located at lower latitudes (estimate \pm SE = 0.180 ± 0.054 , $Z = 3.358$, $P < 0.001$, Fig. 4c, Table S5).

The Chinese prefectures where these physically seized products terminated tended to be inland cities ($P < 0.001$) and were located at high latitudes ($P < 0.001$, Table S5). Xuzhou, in Jiangsu province, was the most important destination, with 13 cases in four trafficking routes from Hainan to Xuzhou (Fig. 4b), which seized 68 individuals, 8896 products, and 24.6 kg of raw tortoiseshells.

4. Discussion

Wildlife crime threatens marine and freshwater biodiversity, but the socioeconomic drivers and geographic patterns of these crimes remain poorly understood. Here, we illustrate how AI can support data extraction and aid the analysis of massive datasets of court cases, which allowed us to determine illegal trade routes and hotspots, as well as identify the taxa that were more intensely exploited. We found that more individual sea turtles were seized or originated from the southeast coastal cities of China, including two hotspots: Qionghai, Hainan province, and Zhoushan, Zhejiang province. Nearly all tortoiseshell products were seized or originated from Hainan. However, more criminal cases were seized in high-tier cities with high per capita GDP. The trafficked products physically seized were terminated in northern inland cities, such as Xuzhou, Jiangsu province, which was an important destination.

These findings indicate that wildlife crimes involving sea turtles occur mainly in the coastlines near islands, aligning with the findings

that crimes are often associated with animals' habitats and roads or viable landing points (Petrossian, 2018; Masés-García et al., 2021). For instance, illegal recreational fishing has been positively related to high reef cover and the presence of islands (Weekers and Zahnnow, 2019). Both Hainan and Zhoushan are coastal islands and are convenient for hunting and transporting sea turtles to inland cities in China. Combined with our findings about main trafficking routes, we concluded that sea turtles are mostly hunted in the southeast coast of China and then delivered to buyers in northern inland areas. This aligns with a market survey that identified Hainan as the hotspot for sea turtle trade in China, with 67 % (4812/7217) tortoiseshell products observed from 57 shops in Hainan (Lam et al., 2011). Besides, previous research showed that products from Hainan were transported northward throughout China (Lam et al., 2011). Our study also found this pattern and further identified Xuzhou as a main destination hotspot, for which we speculated that there are three key reasons. First, Xuzhou has been one of the integrated transport hub cities for several decades (Wang and Wang, 2023; Wang and Chang, 2025). Second, Xuzhou is close to developed regions and high-tier cities, especially the more northern cities or the Yangtze River Delta Area. Combining these two points, Xuzhou may be an ideal transfer city for products originating from Hainan, and then these products would be sold to buyers in developed areas near Xuzhou. The criminal suspects would illegally profit from the price differences between cities with different levels of development. Third, as a non-provincial capital city, Xuzhou may not receive so much attention from law enforcement officers as in high-tier cities, which must be attractive to criminal bands.

The taxa of the seized sea turtles were also related to the two hotspots. The finding that Hainan is a hotspot for crimes involving hawksbill turtles is consistent with a previous survey (Lam et al., 2011), while our study further revealed that Zhoushan is a major hotspot for loggerheads. Over 98 % (207/211) of the loggerheads were seized in Zhoushan, Zhejiang province, whereas 800 individuals were seized and originated from Hainan province, including 73.4 % (450/613) of the hawksbills and 84.2 % (325/386) of the green turtles. Based on internet records, including data from short video platforms, a previous study has shown that loggerheads are the most common sea turtles (79.1 %) nearby Zhejiang, namely, the East China Sea (Chen et al., 2023). Green turtles and hawksbills live in warmer waters than loggerheads (Van Houtan et al., 2016; Ng et al., 2017), such as the South China Sea (Hoh et al., 2022). Accordingly, green turtles are the most common sea turtles around the coast of Taiwan (94.9 %) (Hoh et al., 2022). However, the population and distribution of these two species have not yet been thoroughly investigated in the South China Sea, especially the hawksbills, which compose nearly half of the seized individuals in our sample

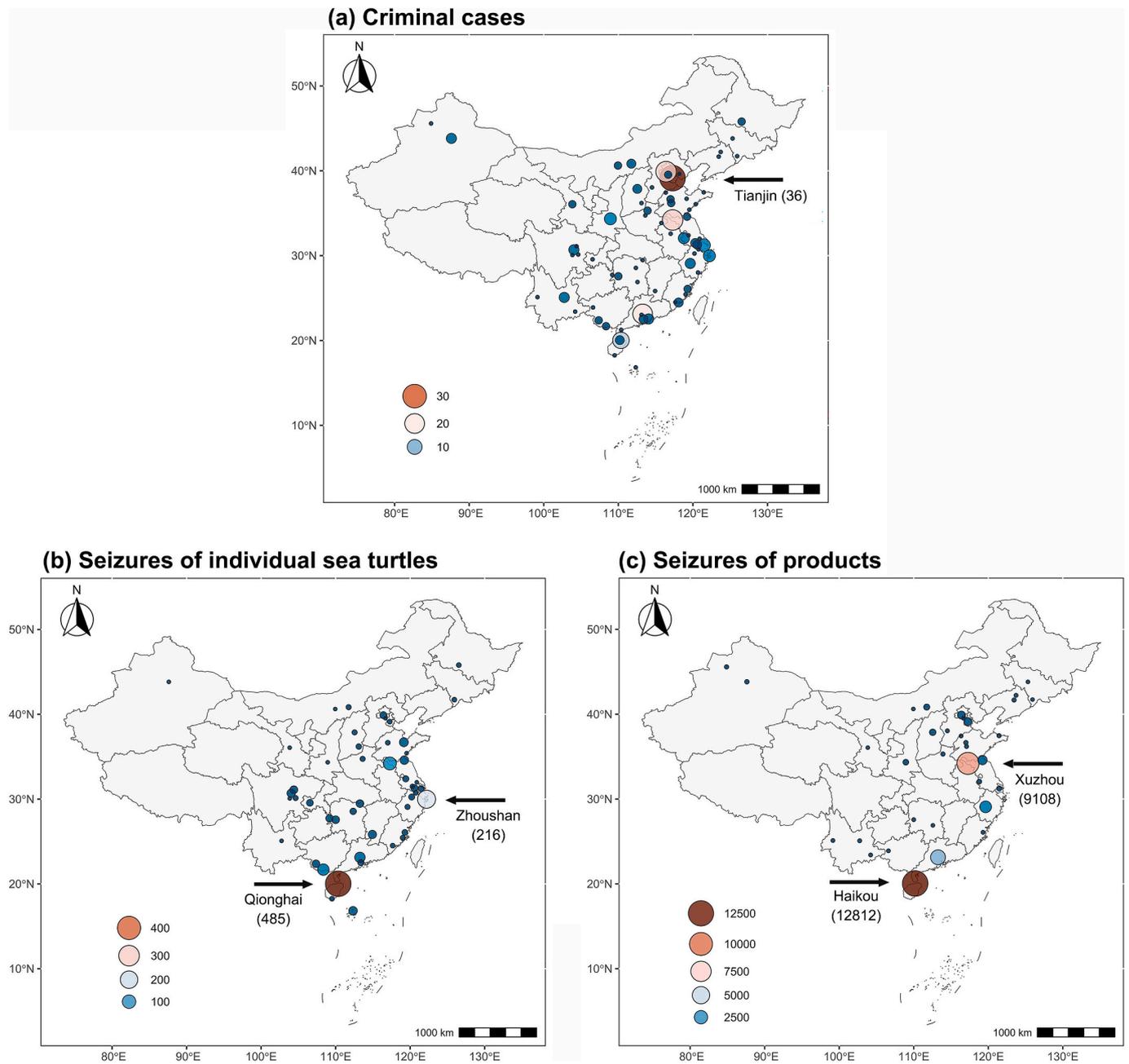


Fig. 3. Geographical patterns of wildlife crimes toward sea turtles in China, including (a) the occurrences of criminal cases, (b) the seizures of individual sea turtles, and (c) the seizures of products. Colors and sizes of the bubbles indicate the total number of cases, individuals, and products seized in each Chinese prefecture. The cities with the highest recorded quantities are indicated using arrows. Enlarged maps are provided in Figs. S1-S3.

(49.6 %, 613/1236). It is very difficult to investigate populations of sea turtles that do not breed in coastal areas, but doing so is crucial for future conservation plans (Hays et al., 2025). The wildlife crimes reported here likely threaten sea turtles in Chinese waters, as the reported cases involve hundreds of loggerhead, hawksbill, and green turtles and nearly 30 thousand derived products. However, only one hunting incident was recorded, as court verdicts only reported the wildlife crimes including seizures (Liang et al., 2023), and other incidents toward sea turtles, such as subsistence hunting (consumption poaching) (Montgomery, 2020), may not be detected. Also, there exist difficulties in determining the primary source of sea turtle crimes, namely illegal fishing or hunting, due to the long coastlines and vast sea areas in China (Fan et al., 2020). Our findings suggest that the two hotspots, Zhoushan, Hainan, and the adjacent waters, should be the primary targets of law

enforcement.

More products were seized in high-tier coastal cities, including two hotspots: Xuzhou, Jiangsu province (31.1 % of the products were seized, 9108/29,323), and Haikou, Hainan province (43.7 %, 12,812/29,323, Fig. 3c). Furthermore, most of the products seized in Xuzhou originated from Hainan province (Fig. 4b). Nearly all the products were made of tortoiseshell. Consequently, Hainan was also the main origin of tortoiseshell products. Similarly, a market survey found that 6208 hawksbill products were sold among nine cities in Hainan in 2019, whereas 1821 pieces were sold in 2020 (Ji et al., 2024). Most products were sold in Haikou and Sanya (Ji et al., 2024). Combining these findings, Hainan province, especially Haikou, is likely an important source of illegal trade of tortoiseshell products and should be closely monitored by law enforcement. Meanwhile, more products were seized or

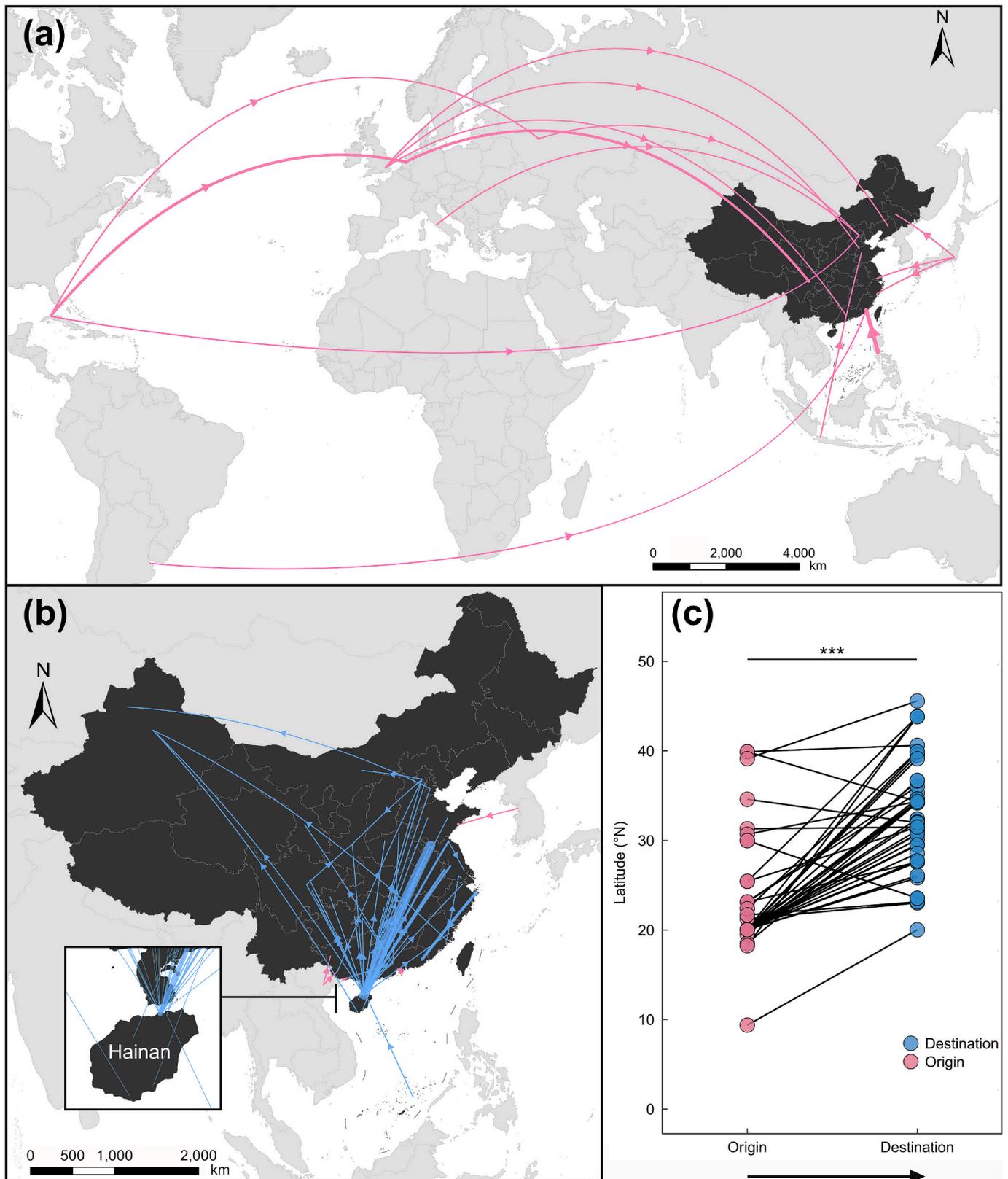


Fig. 4. Smuggling and trafficking routes. (a) Thirteen long-distance smuggling routes. (b) A total of 43 trafficking routes (blue) and five short-distance smuggling routes (pink). The thickness of the lines indicates the number of cases. For instance, the transportation routes originated in Haikou, Hainan province, and terminated in Xuzhou, Jiangsu province (the thickest blue line), in 10 cases. (c) The difference in latitude between the origin and the destination of each trafficking route. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

terminated in high-tier, northern inland cities, suggesting that education about aquatic wildlife conservation should be prioritized in these areas.

The number of sea turtle cases remained low from 2012 to 2017, then increased from 2017 to 2019, but decreased from 2020 to 2022 and rebounded slightly in 2023. Over one-third of the cases (34.9 %, 84/241) converged in 2019. This coincided in time with crimes involving other taxa (Lee and Wong, 2023; Hatten et al., 2024; Xi et al., 2025). For instance, between 2003 and 2022, incidents of giant clam seizures reached a peak in 2019 in Southeast Asia (Lee and Wong, 2023), and between 2010 and 2023, so did the seizures of pangolin products in China (Xi et al., 2025). There might be two main reasons for the fluctuating case numbers. First, the Chinese government reinforced policies and corresponding enforcement to combat wildlife crimes since 2017 (Xiao et al., 2024). Law enforcement for wildlife crimes was rather limited before 2017, so that many crimes went undetected. However, national supervision and enforcement on this matter were largely strengthened from that year, such as the Operation Green Shield (Ministry of Environmental Protection, 2017), which has resulted in a significant increase in seizures and court cases. Moreover, all five species of sea turtles were elevated from second-class to first-class protection in 2021 (National Forestry and Grassland Administration, 2021), and the corresponding penalties have been notably aggravated (Ministry of Agriculture and Rural Affairs, 2019; Supreme People's Court and Supreme People's Procuratorate, 2022).

Second, this reduction in the number of legal cases was likely induced by the outbreak and the epidemic lockdown of COVID-19 from December 2019 to January 2023 in China (Lau et al., 2020; Long and Luo, 2025). Although the origin of SARS-CoV-2 is still controversial, the virus spillover from wildlife (i.e., zoonotic) is widely deemed to be the origin (Singh and Yi, 2021; Ruiz-Aravena et al., 2022). The Chinese government comprehensively banned wildlife consumption in February 2020 (Standing Committee of the National People's Congress, 2020; Xiao et al., 2024), and the public was also less willing to consume wildlife and its products during the pandemic than before (Shi et al., 2020). All these regulations probably constrained illegal smuggling, trade, and trafficking, including the transportation lockdown during the pandemic. Nevertheless, the slight rebound in 2023 seems to suggest the resurgence of sea turtle crimes in the post-pandemic era, so continued monitoring of this issue is still warranted.

Our study has several shortcomings. First, human oversight is needed to check outputs and optimize prompts, which is critical to enhancing the accuracy of AI data extraction. Second, differences in prosecutorial efforts across Chinese prefectures may have introduced a bias in the case numbers. Cities with high case numbers, such as Beijing and Tianjin, may reflect strong law enforcement efforts rather than genuine trafficking intensity. The effort can be directly measured by the number of law enforcement officers, such as police officers, but these are not publicly available in China. We employed the city tier and pGDP as a proxy for prosecutorial efforts, but more accurate proxies of law enforcement should be used in future studies. Third, analyzing the black profit chain is crucial to help future law enforcement and supervision. Our results informed about hotspots and trafficking routes of sea turtle crimes, which are potentially helpful to future black trade chain analysis, yet we were unable to analyze black trade chains based on data from verdicts.

5. Conclusions

While research on wildlife crimes leveraging LLMs is still in its infancy, AI tools are increasingly important for biodiversity conservation (Norouzzadeh et al., 2018; Lahoz-Monfort and Magrath, 2021; Padubidri et al., 2021; Petso and Jamisola Jr., 2023). Here, we analyzed 247 verdicts involving sea turtle crimes in China using DeepSeek-R1 and achieved a data extraction accuracy of 99.38 %. We found that more individual sea turtles were seized in the southeast coastal cities of China, including two hotspots: Zhoushan, Zhejiang province, for the

loggerheads, and Qionghai, Hainan province, for hawksbills and green turtles. Most products were seized in high-tier cities, including two hotspots: Haikou and Xuzhou. Trafficking originated from southern coastal cities, mainly Hainan, and terminated in the northern inland cities, especially Xuzhou. These hotspots we identified could be incorporated into future marine conservation practices and law enforcement. As crimes involving individual sea turtles are of maximum concern, coastal areas of Zhejiang (especially Zhoushan) and Hainan provinces should be prioritized in the future, especially with regard to the illegal hunting of sea turtles.

CRedit authorship contribution statement

Changjian Fu: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Weijia Ren:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation. **Emilio Pagani-Núñez:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Yuqing Han:** Writing – review & editing. **Jincheng Yang:** Writing – review & editing, Visualization. **Huijie Qiao:** Writing – review & editing, Conceptualization. **Zhongqiu Li:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition.

Funding

This study was supported by the Western Light-Key Laboratory Cooperative Research Cross-Team Project of Chinese Academy of Sciences (xbzg-zdsys-202207) and the National Natural Science Foundation of China (32471564).

Declaration of competing interest

We declare we have no competing interests.

Acknowledgements

We thank Yuwen Cheng, Zixi Zhao, and Qin Zhu for their help in data analysis.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.biocon.2025.111511>.

Data availability

Data and R scripts are available from Figshare at <https://doi.org/10.6084/m9.figshare.29949101>. All sensitive details are removed.

References

- Aceves-Bueno, E., Read, A.J., Cisneros-Mata, M.A., 2021. Illegal fisheries, environmental crime, and the conservation of marine resources. *Conserv. Biol.* 35, 1120–1129.
- Aho, K., Derryberry, D., Peterson, T., 2014. Model selection for ecologists: the worldviews of AIC and BIC. *Ecology* 95, 631–636.
- Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. *J. Stat. Softw.* 67, 1–48.
- Bates, D., et al., 2025. lme4: linear mixed-effects models using 'Eigen' and S4. R package version 1, 1–37. Available from: <https://CRAN.R-project.org/package=lme4>.
- Beltrao, H., Magalhaes, E.R.S., Benzaken, Z.S., Sousa, R.G.C., 2021. Trafficking of ornamental fish in the Brazilian Amazon. *Bol. Inst. Pesca* 47.
- Brooks, M.E., Kristensen, K., van Benthem, K.J., Magnusson, A., Berg, C.W., Nielsen, A., Skaug, H.J., Mächler, M., Bolker, B.M., 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R Journal* 9, 378–400.
- Chen, J., Zhou, J., Liu, B., 2023. Records and population status of sea turtles in the Zhejiang Sea area of China. *Biodivers. Sci.* 31, 23082.

- Christianen, M.J.A., et al., 2023. Seagrass ecosystem multifunctionality under the rise of a flagship marine megaherbivore. *Glob. Chang. Biol.* 29, 215–230.
- Clarke, R.V., 1983. Situational crime prevention: its theoretical basis and practical scope. *Crime Justice* 4, 225–256.
- Du, Y., et al., 2024. High risk of biological invasion from prayer animal release in China. *Front. Ecol. Environ.* 22, e2647.
- Fan, Q., Liang, L., Liang, F., Sun, X., 2020. Research Progress on coastline change in China. *J. Coast. Res.* 99 (289–295), 287.
- Godoy, R., Undurraga, E.A., Wilkie, D., Reyes-García, V., Huanca, T., Leonard, W.R., McDade, T., Tanner, S., Vadez, V., Team TBS, 2010. The effect of wealth and real income on wildlife consumption among native Amazonians in Bolivia: estimates of annual trends with longitudinal household data (2002–2006). *Anim. Conserv.* 13, 265–274.
- Gomez, L., Nguyen, M.D.T., 2023. A rapid assessment of the illegal otter trade in Vietnam. *Eur. J. Wildl. Res.* 69, 77.
- Green, A.R., Plowman, C., Mwinyihali, R., Wieland, M., Gore, M.L., 2024. Women and urban wildmeat trafficking in the republic of Congo. *Biol. Conserv.* 293, 110587.
- Hainschwang, T., Leggio, L., 2006. The characterization of tortoise shell and its imitations. *Gems & Gemology* 42, 36–52.
- Hasler, H., Ott, J.A., 2008. Diving down the reefs? Intensive diving tourism threatens the reefs of the northern Red Sea. *Mar. Pollut. Bull.* 56, 1788–1794.
- Hatten, C.E.R., Hadiprakarsa, Y.Y., Lam, J.Y.K., Mak, J., Toropov, P., Dingle, C., 2024. Assessing the legal, illegal, and gray ornamental trade of the critically endangered helmeted hornbill. *Conserv. Biol.* 38, e14358.
- Hawkes, L.A., Broderick, A.C., Godfrey, M.H., Godley, B.J., 2009. Climate change and marine turtles. *Endanger. Species Res.* 7, 137–154.
- Hays, G.C., Laloë, J.-O., Seminoff, J.A., 2025. Status, trends and conservation of global sea turtle populations. *Nature Reviews Biodiversity* 1, 119–133.
- Hoh, D.Z., Fong, C.L., Su, H., Chen, P.Y., Tseng, K.W.H., Liu, M.J.Y., 2022. A dataset of sea turtle occurrences around the Taiwan coast. *Biodivers. Data J.* 10.
- Hu, S., Liang, Z., Liang, D., Liu, Y., Zhong, J., Wei, Q., Lee, T.M., 2024. Quantifying species biases among multidata sources on illegal wildlife trade and its implications for conservation. *Conserv. Biol.* 38, e14351.
- Ji, X., Wang, Z., Zhang, T., Chen, D., Yang, W., Li, M., Shi, H., Lin, L., 2024. Current status and trends of illegal trade in hawksbill turtle products in Hainan Island, China. *Front. Mar. Sci.* 11 (2024).
- Jiang, W.S., Qin, T., Wang, W.Y., Zhao, Y.P., Shu, S.S., Song, W.H., Chen, X.Y., Yang, J. X., 2016. What is the destiny of a threatened fish, *Ptychobarbus chungtienensis*, now that non-native weatherfishes have been introduced into Bita Lake, Shangri-La? *Zool. Res.* 37, 275–280.
- Keel, A.L., Wolf, M., 2020. Towards a classification of marine wildlife crime: marketing strategies to curtail illegal fishing, malicious acts, and waterway pollution. *Psychol. Mark.* 37, 1743–1754.
- Kurland, J., Pires, S.F., Marteache, N., 2018. The spatial pattern of redwood burl poaching and implications for prevention. *Forest Policy Econ.* 94, 46–54.
- Lahoz-Monfort, J.J., Magrath, M.J.L., 2021. A comprehensive overview of Technologies for Species and Habitat Monitoring and conservation. *BioScience* 71, 1038–1062.
- Lam, T., Ling, X., Takahashi, S., Burgess, E.A., 2011. Market Forces: An Examination of Marine Turtle Trade in China and Japan. HongKong SAR, China.
- Lau, H., Khosrawipour, V., Kocbach, P., Mikolajczyk, A., Schubert, J., Bania, J., Khosrawipour, T., 2020. The positive impact of lockdown in Wuhan on containing the COVID-19 outbreak in China. *J. Travel Med.* 27.
- Lee, M.A., Wong, R., 2023. Trading Giants: A Rapid Assessment of Giant Clam Tridacninae Seizures Implicating Southeast Asia 2003–2022. Petaling Jaya, Selangor, Malaysia.
- Liang, D., Giam, X., Hu, S., Ma, L., Wilcove, D.S., 2023. Assessing the illegal hunting of native wildlife in China. *Nature* 623, 100–105.
- Liang, Z., Hu, S., Zhong, J., Wei, Q., Ruan, X., Zhang, L., Lee, T.M., Liu, Y., 2024. Nationwide law enforcement impact on the pet bird trade in China. *Proc. Natl. Acad. Sci.* 121, e2321479121.
- Lin, L., Li, S., Chen, M., Parham, J.F., Shi, H., 2021. Sea turtle demand in China threatens the survival of wild populations. *Isience* 24.
- Long, Y., Luo, W., 2025. Affective lockdown: administrative Chaos and informal repairing in urban China during COVID-19. *China J.* 93, 51–75.
- Mancini, A., Koch, V., 2009. Sea turtle consumption and black market trade in Baja California Sur, Mexico. *Endanger. Species Res.* 7, 1–10.
- Masés-García, C.A., Briones-Salas, M., Sosa-Escalante, J.E., 2021. Assessment of wildlife crime in a high-biodiversity region of Mexico. *J. Nat. Conserv.* 59, 125932.
- Ministry of Agriculture and Rural Affairs, 2019. The Methods for assessing the Value of aquatic Wildlife and its Products.
- Ministry of Environmental Protection, 2017. Notice on Jointly Launching the “Green Shield 2017” Special Action for Supervision and Inspection of National Nature Reserves.
- Montgomery, R.A., 2020. Poaching is not one big thing. *Trends Ecol. Evol.* 35, 472–475.
- National Forestry and Grassland Administration, 2021. List of Wild Animals under Special State Protection., China.
- Ng, C.K.Y., et al., 2017. Regional conservation implications of green turtle (*Chelonia mydas*) genetic stock composition in China. *Chelonian Conserv. Biol.* 16, 139–150, 112.
- Ni, Q., Yu, G., Nijman, V., Nekaris, K.A.-I., Xu, H., Zhang, M., Yao, Y., Xie, M., 2022. Spatial heterogeneity and socioeconomic transformation challenge the prevention of illegal wildlife consumption in China. *Biol. Conserv.* 275, 109751.
- Norouzzadeh, M.S., Nguyen, A., Kosmala, M., Swanson, A., Palmer, M.S., Packer, C., Clune, J., 2018. Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning. *Proc. Natl. Acad. Sci. USA* 115, E5716–e5725.
- Padubidri, C., Kamilaris, A., Karatsiolis, S., Kamminga, J., 2021. Counting sea lions and elephants from aerial photography using deep learning with density maps. *Animal Biotelemetry* 9, 27.
- Petrosian, G.A., 2018. A micro-spatial analysis of opportunities for IUU fishing in 23 Western African countries. *Biol. Conserv.* 225, 31–41.
- Petrosian, G.A., F., P.S., van Uhm, D.P., 2016. An overview of seized illegal wildlife entering the United States. *Glob. Crime* 17, 181–201.
- Petso, T., Jamisola Jr., R.S., 2023. Wildlife conservation using drones and artificial intelligence in Africa. *Sci. Robot.* 8.
- Phasey, H., Griffiths, R.A., Matechou, E., Roberts, D.L., 2023. Motivations and sensitivities surrounding the illegal trade of sea turtles in Costa Rica. *Ecol. Soc.* 28.
- R Core Team, 2025. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing.** <https://www.R-project.org/>.
- Raiaan, M.A.K., Mukta, M.S.H., Fatema, K., Fahad, N.M., Sakib, S., Mim, M.M.J., Ahmad, J., Ali, M.E., Azam, S., 2024. A review on large language models: architectures, applications, taxonomies, open issues and challenges. *IEEE Access* 12, 26839–26874.
- Reynolds, S.A., et al., 2025. The potential for AI to revolutionize conservation: a horizon scan. *Trends Ecol. Evol.* 40, 191–207.
- Ruiz-Aravena, M., et al., 2022. Ecology, evolution and spillover of coronaviruses from bats. *Nat. Rev. Microbiol.* 20, 299–314.
- Schuyler, Q.A., Wilcox, C., Townsend, K.A., Wedemeyer-Strombel, K.R., Balazs, G., van Sebille, E., Hardesty, B.D., 2016. Risk analysis reveals global hotspots for marine debris ingestion by sea turtles. *Glob. Chang. Biol.* 22, 567–576.
- Shao, M.L., Newman, C., Buesching, C.D., Macdonald, D.W., Zhou, Z.M., 2021. Understanding wildlife crime in China: socio-demographic profiling and motivation of offenders. *PLoS One* 16, e0246081.
- Shi, X., Zhang, X., Xiao, L., Li, B., Liu, J., Yang, F., Zhao, X., Cheng, C., Lu, Z., 2020. Public perception of wildlife consumption and trade during the COVID-19 outbreak. *Biodivers. Sci.* 28, 630–643.
- Singh, D., Yi, S.V., 2021. On the origin and evolution of SARS-CoV-2. *Exp. Mol. Med.* 53, 537–547.
- Siriwat, P., Nijman, V., 2018. Using online media-sourced seizure data to assess the illegal wildlife trade in Siamese rosewood. *Environ. Conserv.* 45, 352–360.
- Sleeuwen, SeMv, Ruiters, S., Menting, B., 2018. A time for a crime: temporal aspects of repeat offenders’ crime location choices. *J. Res. Crime Delinq.* 55, 538–568.
- Standing Committee of the National People’s Congress, 2020. The decision of the standing Committee of the National People’s congress on comprehensively prohibiting illegal wildlife trade, Eliminating the bad habit of excessive consumption of wild animals, and Effectively Safeguarding the life, health, and Safety of the People.
- Supreme People’s Court, Supreme People’s Procuratorate, 2022. Interpretation of the Supreme People’s Court and Supreme People’s Procuratorate on Several Issues concerning the Specific Application of the Law in the Trial of criminal cases of destruction of wildlife resources.
- Thialt, L., Weekers, D., Curnock, M., Marshall, N., Pert, P.L., Beeden, R., Dyer, M., Claudet, J., 2020. Predicting poaching risk in marine protected areas for improved patrol efficiency. *J. Environ. Manag.* 254, 109808.
- Thomas-Walters, L., et al., 2021. Motivations for the use and consumption of wildlife products. *Conserv. Biol.* 35, 483–491.
- UNODC, 2024. World Wildlife Crime Report 2024: Trafficking in Protected Species. publications VUN.
- Van Houtan, K.S., Francke, D.L., Alessi, S., Jones, T.T., Martin, S.L., Kurpita, L., King, C. S., Baird, R.W., 2016. The developmental biogeography of hawksbill sea turtles in the North Pacific. *Ecol. Evol.* 6, 2378–2389.
- Vogel, M.L., Hoeksema, B.W., 2024. The role of aquaculture in the international trade of giant clams (Tridacninae) for the aquarium industry (2001–2019). *Aquaculture* 583, 740563.
- Wang, K., et al., 2020. The updated checklists of amphibians and reptiles of China. *Biodivers. Sci.* 28, 189–218.
- Wang, M., Chang, Y., 2025. Research on the constraints and countermeasures for transforming Xuzhou’s transportation advantage into a development advantage (in Chinese). *Journal of Inner Mongolia Science Technology & Economy* 19–22.
- Wang, W., Wang, B., 2023. Lianyungang - Xuzhou - Huai’an are the combined hub cities as per the “14th five-year plan” for the “modern comprehensive transportation hub system”. In: *Landbridge horizon*:15.
- Weekers, D., Mazerolle, L., Zahnrow, R., 2020. Space-time patterns of poaching risk: using the near-repeat hypothesis to inform compliance enforcement in marine protected areas. *Biol. Conserv.* 248, 108652.
- Weekers, D.P., Zahnrow, R., 2019. Risky facilities: analysis of illegal recreational fishing in the great barrier reef Marine Park, Australia. *Aust. N. Z. J. Criminol.* 52, 368–389.
- Weisburd, D., 2015. The law of crime concentration and the criminology of place. *Criminology* 53, 133–157.
- Xi, F., Chao, X., Wu, S., Zhang, F., 2025. Curbing the trade in pangolin scales in China by revealing the characteristics of the illegal trade network. *Sci. Rep.* 15, 2685.
- Xiao, L., et al., 2024. A mixed black and whitelist approach for wildlife trade regulation in China: biodiversity conservation is made of shades of gray. *Conserv. Sci. Pract.* 6, e13062.
- Zhou, X., Booth, H., Li, M., Song, Z., MacMillan, D.C., Zhang, W., Wang, Q., Verissimo, D., 2021. Leveraging shark-fin consumer preferences to deliver sustainable fisheries. *Conserv. Lett.* 14, e12842.